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Hydro-climatic stress, shallow groundwater wells and coping in Ghana's White Volta basin

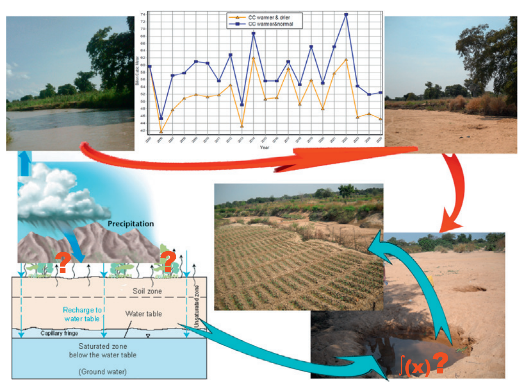
Delali Benjamin K. Dovie [a,b,*], Raymond Abudu Kasei [c]

[a] Regional Institute for Population Studies, University of Ghana, Legon, Ghana
[b] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa
[c] University for Development Studies, Climate Change and Food Security Department, Ghana

HIGHLIGHTS

- Data paucity is undermining climate change - groundwater recharge nexus for management.
- Combined hydro and social models are key to frame human dimensions of groundwater issues.
- Vulnerable populations are adopting shallow groundwater to supplement surface water.
- Ghana's White Volta basin's discharge could support seasonal shallow wells (SSWs).
- Science of shallow groundwater wells is crucial for climate resilience building.

GRAPHICAL ABSTRACT



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ABSTRACT

Debates of the nexus between water-related stresses and water availability for groundwater-dependent irrigation which comprises of non-conventional groundwater abstraction schemes is only recently emerging. The interaction between Seasonal Shallow Wells (SSWs), one of such indigenous abstractions scheme and groundwater recharge remains new to groundwater science and development. The SSWs supplement formal irrigation (e.g. reservoirs) and surface water for dry season agriculture in Ghana's White Volta Basin, yet links with the overall gradient of groundwater is unknown. Therefore, using the Water Evaluation And Planning (WEAP) model and qualitative techniques, the implications of groundwater recharge and surface runoff in their orientation to shallow wells is explored. Standardized precipitation index (SPI) from a regional downscale model for droughts and floods showed increased drought and flood influence on groundwater recharge and irrigation. Enhanced surface runoff water and climate change continuously reduced groundwater recharge by 2030, with decreased stream and water inflows. Irrigation water requirements of reservoirs were computed to be between 173% and 327% of normal reservoir water requirements, yet majority of dams did not meet these requirements especially during the dry season. The basin has history of dryness and exhibited uneven distribution of groundwater, yet recharged water of unsaturated soil moisture zones made water available to the SSWs. The SSWs were patronised mostly by women and farming households based on perceptions of limited cost, less sophistication and no formal regulatory measures. The paper therefore provides framework for establishing links between the mechanics of SSWs, and existing climatic and hydrologic conditions for informed groundwater development.

* Corresponding author at: Regional Institute for Population Studies, University of Ghana, LG96, Legon, Ghana.
E-mail address: dbdovie@rips-ug.edu.gh (D.B.K. Dovie).

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report confirms climate change as posing significant risks to natural and human systems (IPCC 2014). Globally, the impacts of climate change on groundwater resources is gradually emerging, blamed on severe data paucity and little interest (Aslam et al. 2018; Ertürk et al. 2014; Kahsay et al. 2018; Nkhonjera and Dinka 2017). In West Africa, warming has increased from 0.3 °C in the Gulf of Guinea to 1.0 °C in the Sahel and accompanied by frequent droughts which have prevailed over a two-decade period (Druyan 2011; IPCC 2007, 2014). Dry conditions and droughts have for instance had direct bearing on the Volta River Basin (Lebel and Ali 2009), experiencing higher interannual variability, and subsequent delayed onset and early retreat of the monsoon season (Biasutti and Sobel 2009; Seth et al. 2013; Sylla et al. 2010). There is protracted growing season (Cook and Vizy 2012) and extensive torrid, arid and semi-arid regimes as the moist climate zones recede further south (Elguindi et al. 2014; Sylla et al. 2015). An important outcome of drought has been the increased use of groundwater at shallow depths mostly by smallholder farmers and rural families in drier regions (Ertürk et al. 2014; Liebe et al. 2005; Mdemu et al. 2009). The "Seasonal Shallow Wells (SSWs)", dug in dried streams or river channels during dry seasons for irrigation agriculture characterise the White Volta basin yet the mechanics linking groundwater recharge and water availability are unknown, creating uncertainties around its adoption for formal irrigation. Globally, there is immense limitations of knowledge on groundwater recharge rates including groundwater stress, or groundwater–surface water interactions and land use change (Bates et al. 2008; Friesen et al. 2017; MacDonald et al. 2012; Stoll et al. 2011). Hence the paper explores how groundwater recharge and water availability under conditions of climate change and drought inform the adoption of groundwater abstraction practices such as the SSWs and its mechanics within the White Volta basin in Ghana. Globally, substantial uncertainty in precipitation projections across various latitudinal regions showing drier future scenarios and water stress are traced further to climate change (Ali et al. 2012; Antwi-Agyei et al. 2016; Bovolo et al. 2009; Dai et al. 2004; Döll 2009; MacDonald et al. 2012), predicting decline in precipitation in the range of 0.5–40% with an average of 10–20% by 2025 (e.g. Kasei 2009).

It is projected globally that land area subject to increasing water stress from climate change would more than double that with decreasing water stress by the 2050s (Döll and Flörke 2005). Computed groundwater recharge could decrease by more than 70% by the 2050s in south-western Africa under all four climate change scenarios (the ECHAM4 and HadCM3 GCMs with the SRES A2 and B2 emissions scenarios) (Döll and Flörke 2005). Notwithstanding the decreasing groundwater recharge rates and depths globally, groundwater resources remain vital to surface water availability (Bovolo et al. 2009; Döll 2009). In some drier areas of sub-Saharan Africa, reductions in stream flow of more than 50% are confidently predicted such that many perennial streams would become seasonal and others drying up permanently (Sadoff and Muller 2009). The projected shortened rainy season attributed to greater warming (~ +6 °C) in the Sahel and the Sahara deserts (Diallo et al. 2012; Mariotti et al. 2011) will be more pronounced by the end of the 21st century (Sarr 2012). Unfortunately, not all countries may be endowed with sufficient resources to develop groundwater resources because of needs to first overcome water infrastructure problems (Bates et al. 2008). The White Volta basin has experienced its share of observed significant decreases in annual rainfall and river discharges and projected to be aggravated by climate change (Addai et al. 2015; Gyau-Boakye and Tumbulto 2006; Kankam-Yeboah et al. 2013; Obuobie et al. 2012; Oguntunde et al. 2006). Yet, some groundwater resources of the White Volta are sufficient to optimize dry season irrigation when reservoirs and streams in the basin ran dry (Bharati et al. 2008; Lutz et al. 2007; Mdemu et al. 2009; Sternberg and Paillou 2014), making shallow wells feasible complement. Therefore, development that focuses on water security represents sound early and effective adaptation (Bates et al. 2008; Jimenez Cisneros et al. 2014; Ludwig et al. 2011; Ngcobo et al. 2013). Seasonal Shallow Waters (SSWs) are one of such development because they provide timely, more sustainable cost and operational option than deep groundwater wells, especially for smallholder farming, and also known to reduce salinity and water logging associated with pumping deep groundwater (Morway et al. 2013; Satchithanantham et al. 2014; Wichelns and Qadir 2015). The SSWs sustain year-round farm employment in the drier northernmost regions of Ghana, important to Integrated Water Resources Management (IWRM) in savannah ecosystems. In addition to the socioeconomic importance of the SSWs, its mechanics merit understanding as source of artificial groundwater recharge, protection and preservation of wetlands as channels for directing high runoffs from heavy storms into the aquifers at the beginning of the rains.

2. Methodology

2.1. Study site description

The White Volta basin is shared between Ghana and Burkina Faso (Fig. 1), lying between latitudes 8°50′N–11°05′N and longitudes 0°06′E–2°50′W, and part of the larger Volta basin. The Volta basin is located between latitudes 5°30′N and 14°30′N and longitudes 2°00′E and 5°30′W, located mainly in Ghana (40.2%) in the downstream and Burkina Faso (42.6%), and Togo, Côte d'Ivoire, Mali, and Benin sharing the remaining. The Basin is drained by several major rivers such as Black Volta, the Red Volta as its tributary, Oti River, and Lower Volta in addition to the White Volta. The White Volta drains 50,000 km^2 of Ghana, covering 20% of the country (Water Resources Commission 2008). The Red Volta and Sisili are the tributaries within the Birimian geological formation of significant Voltaian system comprising the wet south, transition zone, and tropical north climatic zones of mean annual rainfall between 500 and 1100 mm (UNEP-GEF Volta Project, 2011). The annual groundwater recharge range in the White Volta basin is between 3 and 11% of annual precipitation, translating into 30 mm and 110 mm of rainfall, respectively (de Condappa et al. 2009; Obuobie et al. 2012; WRC 2008). Basement rocks of the basin are largely crystalline with little or no primary permeability. The extraction of groundwater is associated with locations where the rocks are heavily fractured and/or highly weathered. Yet, wells can yield beyond 600 l per minute of water when they are deep enough (Water Resources Commission 2010). An inventory of currently operating wells and boreholes in the basin suggest that the wells and boreholes drilled through the Birimian aquifers even at relatively shallower depths (around 70 m) are relatively high yielding, with average yields of about 60 l/min in some locations (WRC 2010). In the Savelugu and surrounding areas, average yields exceeding 45 l per minute have been noted for wells drilled through the mainly sandstone aquifers of the Middle Voltaian. Where prolific boreholes and wells are identified in locations farther away from the demand centers, these can be mechanized and connected with pipes for irrigation purposes.

Irrigated agriculture in the White Volta basin is widespread and undertaken by over 60% of the population but there are bigger potentials of increased production (Dovie 2010; UNEP-GEF Volta Project 2013). Although the physical characteristics of the northern sector of the country in particular, is most suited for irrigated and mechanized agriculture, these schemes are rarely practiced except in few areas such as Botanga, Libga Golinga (northern region) and Vea and Tono in the Upper East region. There are also a number of small multipurpose dams and dugouts provided to communities for use especially to serve dry season needs. The construction of about 44 dugouts and 31 boreholes were initiated under the National Livestock Project to provide water for multiple uses in various communities by December 2010 (GoG 2010). The two largest irrigation schemes (Tono and Vea) in the Upper East region are used to support all year-round production of rice and vegetables.

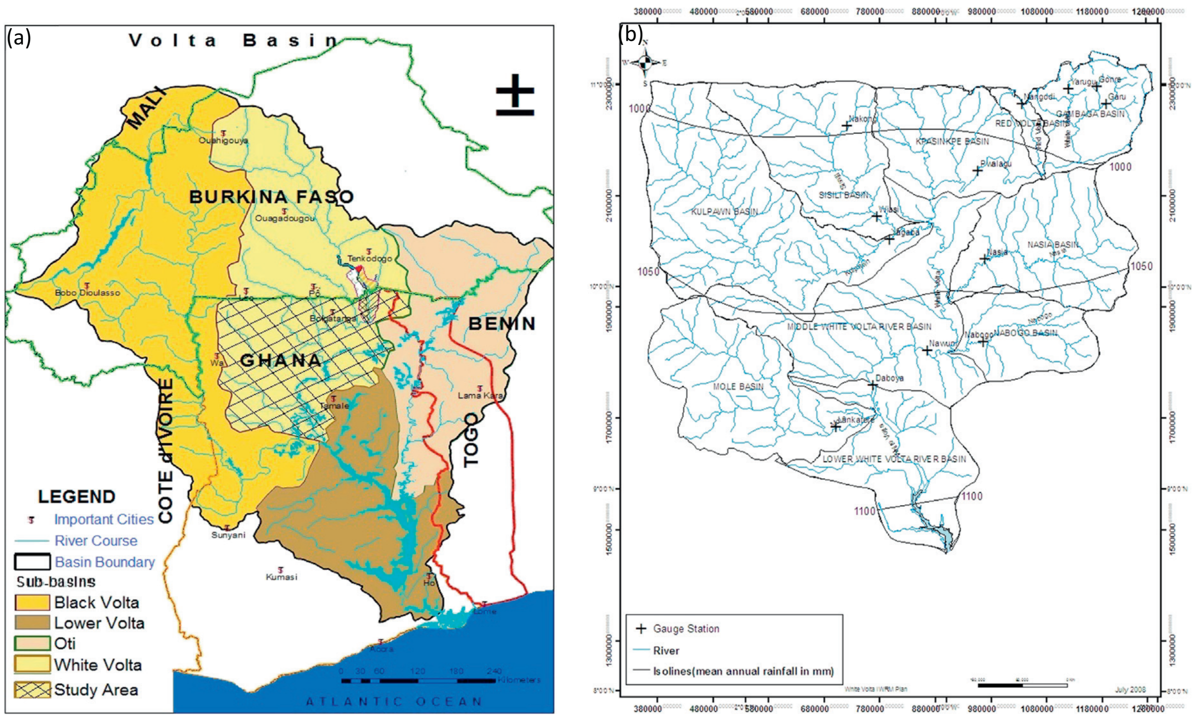

Fig. 1. (a) Map of the entire basin of Volta River showing the White Volta basin and the study area, and (b) the drainage map of the White Volta basin and the major sub-catchments.

2.2. Methods

A mixed method approach of quantitative and qualitative was used for the study. The quantitative component from the geophysical perspective was made up of hydrological and climatic models whilst the qualitative aspects were socioeconomic-dependent and involved participatory learning approaches (PLA). The source of data was the "Climate Change Adaptation through Integrated Water Resources Management in the three Northern Regions of Ghana" project of Ghana's Water Resources Commission (WRC).

2.2.1. Hydroclimatic assessment of groundwater resources

The hydroclimatic assessment (Fig. 2), emphasised the quantum of water available within the White Volta basin, associated demand by diverse stakeholders and the extent of the impacts of climate change. The rainfall to groundwater recharge nexus is well known and established by several reports, e.g. Martin (2006), who estimated the recharge within the White Volta catchments to be 5% of rainfall. The Standardized Precipitation Index (SPI) was used to assess the rarity of droughts or low flows. The SPI is based on the cumulative probability of a given rainfall event occurring at a gauge station. The SPI values represent (from −3

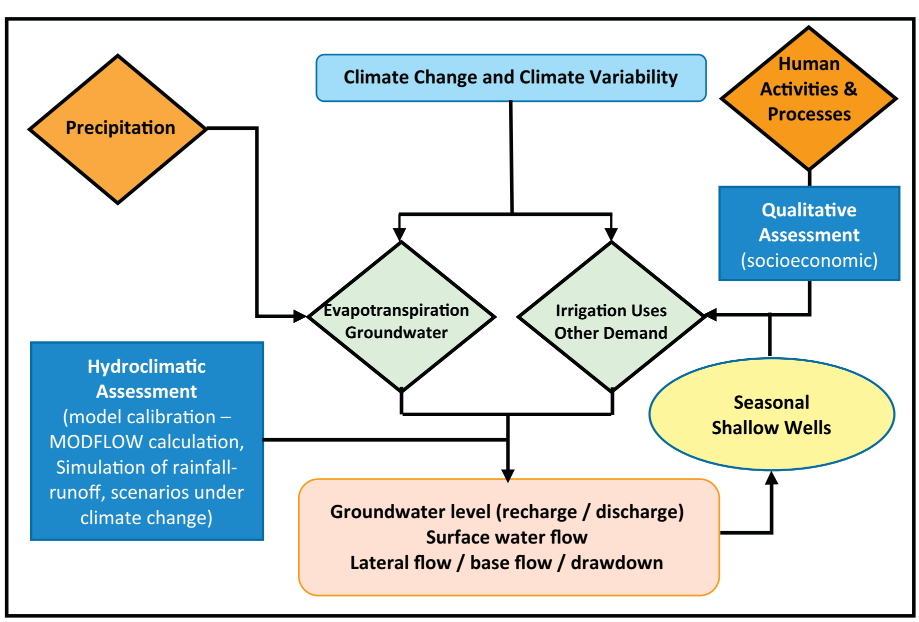

Fig. 2. Schematic drawing of the hydrological assessments comprising the Water Evaluation And Planning (WEAP) model (SEI 2005), development of climate change scenarios, and qualitative assessments of socioeconomic dynamics related to water availability and demand.

to +3) the standard deviation of the precipitation series. Negative values represented precipitation deficits (drought years), whilst positive values stood for precipitation excesses (wet years).

Water allocation and demand was modeled using the Water Evaluation And Planning (WEAP) model (SEI 2005), a planning and decision-making tool that analyses the allocation of water for various uses such as for livestock and irrigation (Fig. 2). WEAP operates on the basic principle of water balance accounting involving supply sources such as groundwater and reservoirs, withdrawal and transmission, and water demand and requirements (SEI 2005). Using a semi-distributed approach, the White Volta basin was divided into nine hydrologic sub-catchments and output combined with land-use data which was obtained from the IWRM plan for the White Volta basin (WRC 2008). WEAP is an integrated framework of hydrology and water allocation elements for a typical basin, and the various water uses represented as the "demand". The WEAP model was used to simulate river discharges, groundwater recharge and actual evapotranspiration (ETP). The simulation of the groundwater resources flow of the White Volta Basin was based on a finite difference groundwater flow simulation code, MODFLOW-2000 (Harbaugh et al. 2000) incorporated into the Groundwater Modeling System (GMS 6.5). Water samples were taken from dugouts ranging from 1.5 m to 3.5 m in depth across the saturated and unsaturated zones spanning the soil horizons. To estimate the hydraulic conductivity of the soils, soil samples were collected and analyzed for (i) bulk density, (ii) porosity, (iii) electrical conductivity, (iv) major ion chemistry, in addition to (v) pumping test data. Desired match between the observed and computed hydraulic heads at various locations of the dugouts was obtained by varying the hydraulic conductivities, recharge, riverbed conductance, and evapotranspiration values using the observed hydraulic heads at groundwater levels. The conceptualization of the boundary and initial conditions of the flow simulation model was performed within the GMS 6.5 environment using the GIS tools in the map module. The sub-catchments were conveniently used as coverage in the conceptualization and initial hydraulic parameters assigned to each zone or coverage, represented averaged hydraulic parameters from all wells.

2.2.2. Simulation of rainfall-runoff model

A conceptual rainfall-runoff model, the NAM model of the Danish Hydraulic Institute (DHI), was used to model river flow in selected catchments in the White Volta Basin of Ghana. The hydro-meteorological input requirements of the model were (i) observed average rainfall, (ii) temperature, (iii) potential evapotranspiration (ETP) and (iv) river discharge. The input parameters for the observed discharge related to surface and subsurface storage capacity, surface and interflow runoff and base flow generation. The output parameters of the model were, simulated river discharges and average catchment groundwater recharge and actual evapotranspiration for the timescale used. River flow was therefore derived for seven catchments of the White Volta for their networking (i.e. Yarugu and Pwalugu on the main White Volta River, Nangodi on the Red Volta, Yagaba on the Kulpawn, Wiasi on the Sissili, Nasia on the Nasia and Nabogo on the Nabogo tributaries of the White Volta). The gauging stations for the selected catchments had relatively fewer gaps in the observed runoff records and existing rainfall and computed ETP (based on the GLOWA Volta Project, GVP) from 1951 to 2009, and each catchment modeled to suit river discharge prediction for the catchments in order to predict monthly river flows at the selected gauging stations. Historical records on meteorological data (i) rainfall, (ii) temperature, (iii) relative humidity and other climatic data from the Ghana Meteorological Agency (GMet) provided average datasets of climate variables. These data sets formed the input data for the WEAP model. The impact of climate change on the river flow for each catchment was ascertained by running the respective validated model with projected rainfall and the ETP series. The ETP series were computed from the Penman-Monteith formula for various catchments in the Volta Basin (including those used in this study).

2.2.3. Modeling precipitation, groundwater resources and water availability

Following the calibration and validation of the WEAP model, climate scenarios were created by forcing WEAP with temperature and rainfall data over a period of 20 years using 2010 as the base year for the simulations (i.e. keeping all water demands as they were for the year 2010). Adopted decadal increasing rainfall trend in the West Africa sub-region reflected the consensus of no change in rainfall in West Africa, whether it will increase or decrease (IPCC 2007). Four different drought categories were derived from the SPI analyses based on McKee et al. (1993). It is observed that a year with SPI lower than −2.0 usually affected nearly 75% of the Volta basin (Kasei, 2009). This shows that major parts of the region experience extreme drought conditions during these years. Drought intensity and frequency analyses for the Volta Basin reveals an average return period of 10 years for a moderate drought (SPI between −1 and − 2; Fig. 3). In the 1960s and 1970s, dry years occurred at an interval of 3–4 years, but from the early 1980s till 2006, dry periods occurred almost every year, indicating an increase in the frequency of dry years in the basin with a probability of 0.7. The drought of 1983/84, which affected the entire basin, had a much lower probability compared to other drought events. Dry years have become more frequent since the beginning of the 1980s and have occurred at shorter intervals. The areal extents of this dryness, though not severe, have been increasing over last 20 years. Between 1983 and 2001, the basin experienced at least 4 moderately dry years covering over 50% of the area. Increased water requirements for projected increased populations and water consumption per capita, projected irrigation development and increased per capita irrigation water demand under climate change as well as increased small reservoirs population were integrated in the scenarios. The scenarios took into account existing water conservation infrastructure and implications for irrigation development. In the application of the WEAP model for the assessment of water resources availability and demand, two main categories of climate change scenarios were considered. The assessment of water availability was done using the second scenario 'drier' conditions since that represents the worse case scenario in terms of water resources availability. However, the first case scenario 'warmer' condition was also used for the purpose of comparison as follows:

1. Increase in temperature resulting in increase in evapotranspiration hereby referred to as 'warmer' but normal condition;
2. Increase in temperature resulting in increase in evapotranspiration as well as decrease in annual rainfall hereby referred to as 'warmer' and 'drier' conditions.

The scenarios were developed on the assumption that there will be 2 °C rise in temperature within the next two decades. For this temperature increase, we term the condition "warmer".

For a drier situation, the 0.5^0 grid spacing of the CRU dataset overlaid on the basin is moved twice southward, corresponding to an arbitrary 1^0 shift of isohyets in which case, the dry north east trade winds dominate the region, resulting in decreased precipitation over space and time.

2.2.4. Qualitative assessment of water stress and mechanics of SSWs

Participatory learning approach (PLA) was used to examine the perception of the local population of water stress and roles played by climate change, as major decision-making component on sustainability of water resource use (Hermanowicz 2008). It involved (i) direct field observations of the physical state of water resources and changes thereof between the dry and wet seasons, (ii) participant observation which covered how local population engaged in irrigation activities including the preparation and harnessing of water from the shallow wells,

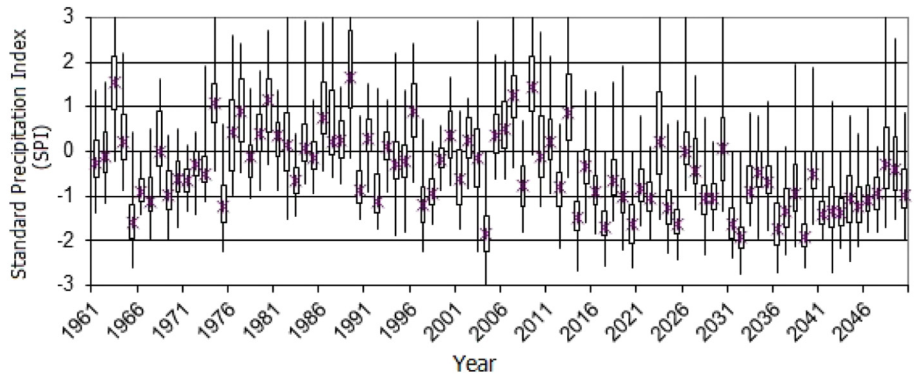

Fig. 3. SPI graphs plotted against years for the catchment (northern part of the Volta Basin) with confidence intervals.

(iii) farmer field engagement (FFE), using purposive sampling to interact with farmers on their farms, and (iv) communal meetings on the bigger outlook of opportunities, challenges and potential of the SSWs in the context of climate change and emerging response measures. The PLA provided rapid assessments of SSWs. Four districts purposively sampled were Bawku East district bordering Burkina Faso, Kasena Nankana East and West districts, and Bolgatanga municipality, to precisely aid descriptions of the SSWs, and their development including opportunities and barriers they offered and policy implications. Informal interviews were conducted with the local population mostly of farmers, women, young adults, and livestock herd boys about hydroclimatic challenges within the basin, the origin, practice and implementation of the SSWs. Where the collective view of a community was required, tailored communal meetings were held. The communal meetings helped mainstreamed the socio-economic issues with the geophysical outcomes which provided appropriate triangulation of results and ensured accuracy of the individual responses.

3. Results

3.1. Groundwater recharge

The distribution of hydraulic heads in the White Volta basin suggests the highlands as the preferred direction of groundwater flow and generally also the major recharge areas, and the lowlands as discharge areas (Fig. 4). The recharge range estimated from the WEAP was 2780 m^3/day to 14,000 m^3/day, translating into 1.01 million m^3/year and 5.10 million m^3/year of water, respectively. The total annual groundwater recharge computed in the water budget for the entire White Volta basin is approximately 4062 million m^3/year, averaging

Fig. 4. Calibrated groundwater recharge rates in the White Volta basin (in m^3/day).

Table 1
Annual sub-catchment groundwater recharge from Precipitation and groundwater budgets.

Sub-catchment	Recharge (mm/yr)	% of annual rainfall	Flow budget (m^3/yr)
Kulpawn	87.60	8.7	2,626,129.30
Sisili	69.35	6.9	1,002,030.77
Kpasenkpe	69.35	6.9	822,411.46
Gambaga	69.35	6.9	758,642.10
Mole	69.35	6.9	1,153,070.08
Lower White Volta	58.40	5.8	881,499.69
Middle White Volta	54.75	5.5	1,896,164.80
Nasia	40.15	4.0	593,407.85
Nabogo	40.15	4.0	490,650.30

451 million m^3/year per sub-catchment. The recharge on catchment basis (Fig. 4) and the associated groundwater budget was highest for Kulpawn and lowest for Nabogo and Nasia (Table 1). The groundwater budget represents the quantitative groundwater computed per each catchment based on the recharge from precipitation with the exception of storage hence the lower values in Table 1 than the actual budget is characteristic of steady state models.

The climate change under drier state condition scenario was very pronounced and all water demand types characterized by normal and dry years in the scenarios that represented a typical trend of annual precipitation. The model estimates a mean 12% reduction in precipitation under "drier" condition relative to the "normal" setting over the same period (2010—2030). The total annual volume of rainfall ranges from estimated 42 billion m^3 in a very dry year under "drier conditions" to an estimated 74 billion m^3 in a very wet year with "normal" conditions (Fig. 5a). The volume of water under warmer and drier conditions was

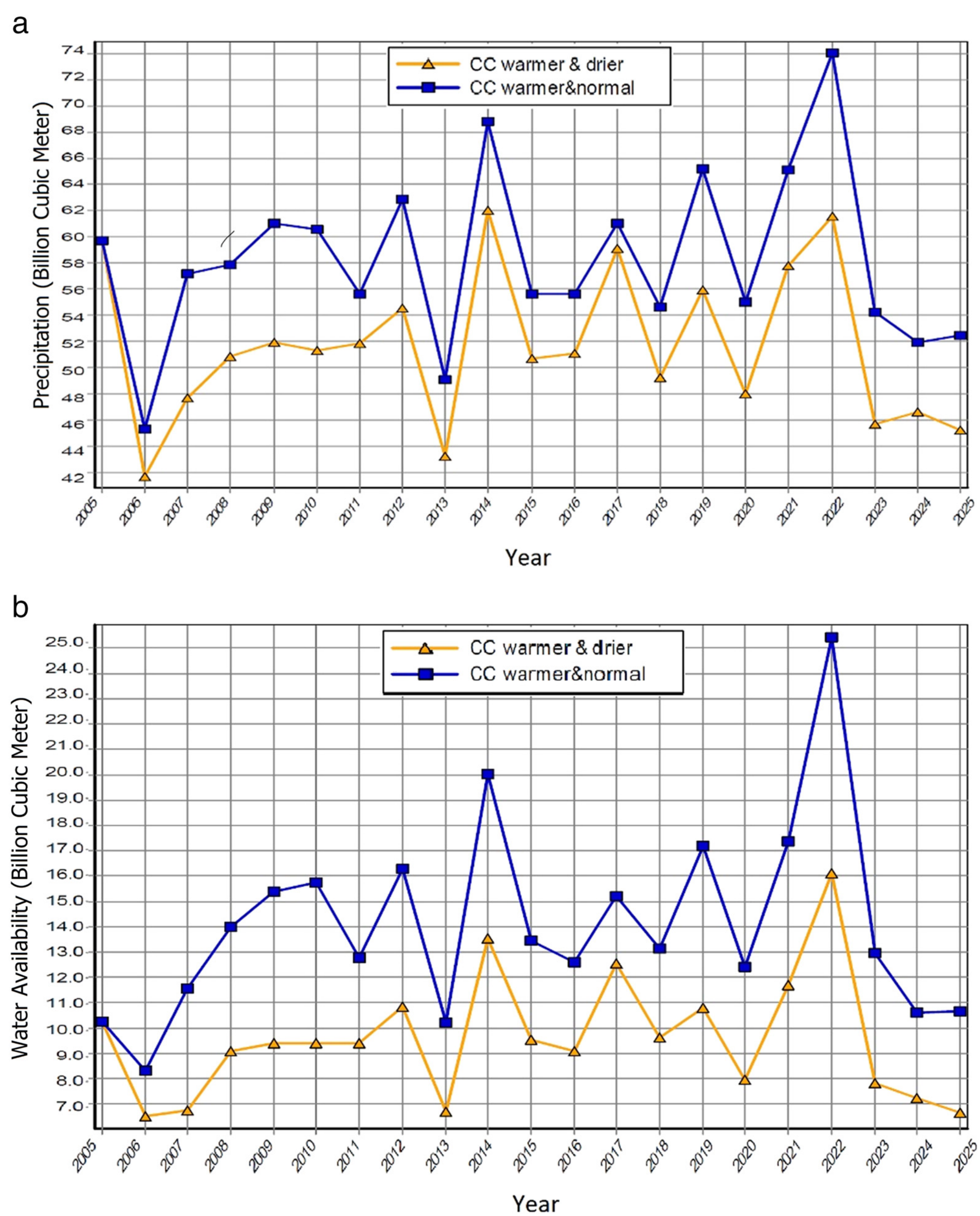

Fig. 5. a. Total annual volume of precipitation in the White Volta basin for typical climate change scenarios b. Variation of total annual volume of water available for potential exploitation under climate change.

Table 2
Total volume of a monthly inflow during dry year under two conditions of climate change.

Catchment name	"Normal" conditions under climate change (million m^3)	"Drier" conditions under climate change (million m^3)
Nawuni	30.0	17.0
Lower White Volta	16.0	13.0
Kulpawn	5.0	3.6
Mole	5.0	3.6
Sisili	3.8	2.6
Nasia	1.3	0.8
Kpasenkpe	1.1	0.8
Pwalugu	1.7	0.7
Nabogo	0.4	0.3
Total (million m^3)	64.3	42.4

projected to decrease for all years and most severe in 2025 compared to the volume of water under the warm and normal climate conditions (Fig. 5a). An estimated 24% of the total annual precipitation was available for exploitation as infiltration or runoff water under "normal" conditions of climate change, decreasing to about 18% under "warmer and drier" setting (Fig. 5b).

3.2. Water inflows, climate change and irrigation water demand

The White Volta basin experiences decreased water flows from November annually and marking the end of the rainy season till the following April. At least 115 million m^3 and 170 million m^3 of water corresponding to the total volume of all the dry months between November and April of each year are distributed unevenly in the basin. Total volume of monthly stream inflow to the various catchments within the basin ranges from 0.3 million m^3 to 17 million m^3 in Nabogo and Nawuni, and 0.4 million m^3 to 30 million m^3, respectively, for very dry years under "drier" and "normal" condition of climate change (Table 2). Thus a 34% reduction in total inflow for the White Volta basin was expected under drier conditions of climate by 2030 denoting 64.3 million m^3 water to 42.4 million m^3 (Table 2). Within the same period, irrigation requirements for all existing irrigation schemes were fully satisfied under "normal" climate conditions. Water requirements of the "drier" conditions of climate change were however met by only two of the six large irrigation schemes in the basin with the remaining four faced with varying degrees of water deficits. For small reservoirs operating under "normal" conditions of climate change, demands are satisfied for three catchments which experience unmet water demand but worsened under "drier" reservoir conditions of climate change (Table 2). Irrigation water requirements for existing water storage schemes at the beginning of the simulation increased over the period from a minimum 173% for the large dams to maximum 327% for smaller schemes by the year 2025.

Table 3
Existing and projected annual water requirements for irrigation schemes over 2030.

Irrigation scheme	Annual water requirement (Mm^3)	
	Start-up/Current year (2010)	End of period (2030)
Inter Tropical Food Company (ITFC)	5.5	18.0
Bontanga	5.5	18.0
Nasia-Nabogo	7.5	20.0
Nawuni-Daboya	7.5	20.0
Vea	7.5	20.0
Tono	27.5	45.0

Irrigation requirements for all existing irrigation schemes and their envisaged expansions as well as projected development were fully satisfied under "normal" climate change conditions. However, under "drier" conditions of climate change, only Tono irrigation and Nasia-Nabogo irrigation water requirements are met (Table 3).

3.3. The seasonal shallow wells

The SSWs have different designs for harnessing water at shallow depths, based on the indigenous knowledge of the hydrology and expected flow orientation of water within the basin. The SSWs have been part of numerous innovations by subsistence farmers to increase the availability of water during the dry season, dating back several years but became widely used in the late 1990s. Accordingly, the more water that was extracted from the wells, the quicker the wells refilled, and are therefore considered renewable, within the shorter dry season periods. Users of SSWs concluded that water in the wells was replenished from subsurface stream flow and unsaturated zones. These flows allowed users to practice irrigated agriculture during drier months to complete all year-round agriculture. Communally, the SSWs were a convenient source of livestock watering for its shallow depth whilst they reduced mobility of pastoralists in search of water for their animals, and for easy access by women and children also as domestic water source. The SSWs compensated for the drastic reduction in access to water from lowering water tables of traditional tube wells and boreholes attributed to changing rainfall regimes and protracted in recent times compared to the mid-1990s (Table 4). The local population unanimously and strongly suggested climate change as the most single important driver of the hydraulics of water resources of the basin. Farmers recounted experiences the impacts of extreme droughts in early 1980s and mid-1990s (Table 4). Although the knowledge of the practice of SSWs existed, it was perceived to have been a preserve of poorer and least resourced households.

Table 4
Historical perception of occurrence of drought as indicator of climate change within the White Volta basin in the three northernmost regions of Ghana.

Year	Event	Severity	Effects
1968–73	Below average rainfall records coupled with wilting of crops	Very severe	Water imbalances that adversely affected land resources and crop production
1982–85	Generally dry spells from drastic reduction in rainfall amounts	Very severe	Low crop yield and death of livestock
1990–92	Erratic rainfall observed for the whole season	Very severe	Famine, water imbalance, decline in crop and animal production
2006	Erratic rainfall during 2nd and 3rd quarters with dry spells in August	Severe	Low production levels of crops were recorded resulting from these dry spells
2007	Less than normal rainfall in 1st and 2nd quarters resulting in drought	Severe	i. Early millet suffered low yields and low quality grain ii. Low or non-existent dry season grain stocks iii. Crops such as maize experienced low germination rates, stunting and yield failure iv. Groundnut plants flowered pre-maturely, aborted and low yield
2008	Dry spells in the months of April and May, prolonged to July	Severe	i. First rains in April and May ii. Wilted crops (e.g. cowpeas, maize, sorghum and yams) iii. Prolonged June–July drought in also slowed land preparation and planting

Users of SSWs especially farmers attributed increased adoption to (i) little or no cash investment depending on the extent, (ii) labor non-intensity, (iii) easily implementable once flow direction detected, (iv) reliability and sustainability within the dry season, (v) less technical intervention, (vi) common property resource with no land tenure or ownership arrangements, and (vii) gender sensitive and less drudgery for women and children. According to farmers, some SSWs have been improved using improvised artificial recharge strategy by creating artificial barriers with sand filled bags during the rainy season similar to how sand dams work, as huge amounts of silt from upstream is deposited behind the barriers. Accordingly, once streams completely dried up, the top soils were scooped to shallow depths at predetermined distances from the artificial sand bag barriers to allow large quantities of water to be abstracted. Major perceptions of farmers about the mechanics of the SSWs and the hydrology are:

a) water flowed into the wells laterally from the unsaturated zone tangential to the piled-up silt around the sand bags rather than an updraft.
b) water was available from SSWs at depths of 1.5 m beyond which only deeply sunk wells such as boreholes was feasible.
c) limited knowledge of how long SSWs could be sustained in the face of climate change and links with durability of water from the rainy season flow.
d) there was increased dryness of the lower areas of the White Volta through to the upper areas closer to Burkina Faso from loss of vegetation attributed further to poor onset of rains, rather than poor land use.

4. Discussion

4.1. Groundwater recharge and flows

The study shows that the hydraulic properties of the White Volta terrain vary significantly even within very short distances. Subsequently the most prudent way to understand recharge and water flows was at the sub-catchments levels which differ in orientation, size and geophysical characteristics and importantly, the scale of land uses and land cover changes. For example, excessive water withdrawals from potential water stress environments can exacerbate the impact of drought and attendant consequences for groundwater resources. This is explained by the perception of the local population that SSWs were not always successfully harnessed from all sub-catchments within the basin. Rainfall estimates by L'Hôte et al. (2002) pointed to decrease in annual precipitation southwards over the years in the northern part of the basin. Low flows hazard of water within the sub-catchments depended on many factors such as (i) rainfall deficit, (ii) dry spell occurrences, (iii) maximum value of the cumulative rainfall deficit and (iv) duration of rainfall deficit. Thus, rainfall deficit was expected to extend to larger areas in the basin in future as groundwater and surface water in the basin reveal high susceptibility to dryness (Table 2). Therefore, intensified dryness would be experienced within the major catchments of the White Volta basin namely Nabogo, Pwalugu, Kpasenkpe and Nasia, with small reservoirs significantly impacted (Table 2). In the longer term, there will be pronounced shortfalls in water for the projected years of the impacts of climate change on precipitation through 2025 under "drier" conditions (Fig. 5a) which undermines the average monthly coverage in water demand of small reservoirs and large irrigation schemes. The impacts of dryness on groundwater resources in terms of reduced recharge (Fig. 5b), especially of subsurface storage because they exchanged heat directly with the ground surface have been observed elsewhere (Aslam et al. 2018; Kløve et al. 2014; Taylor and Stefan 2009). Stream flows during dry periods from November to April in the White Volta basin is severely hampered, coinciding with paramount demand for water to meet irrigation needs. The analysis confirms that there will be increasing risk of drought conditions and deficits in the water requirements for various uses as one moves further up from the Lower White Volta to the Nabogo catchment (Table 2).

The perceptions of the local population that climate change was changing the state of groundwater resources are confirmed in the quantitative analysis of groundwater recharge. It should be noted that the total volume of monthly stream inflow is not evenly distributed in the basin as some catchments are least biophysically stressed than others, similarly to observations by Obuobie et al. (2012). These are attributed to biogeophysical drivers and climate change is of immense concerns for the local population in sustaining the SSWs (Fig. 6). Because reservoir storage in the basin is independent of the pattern of irrigation water demand in the basin, there is need to diversify irrigation water sources using small water abstraction interventions such as dug-outs, reported elsewhere by Bharati et al. (2008). The combined impacts of climate change and related socio-economic determinants such as changing consumption patterns increase stress on groundwater resources (Aslam et al. 2018; Green et al. 2011; IPCC 2014). Yet global climate models and scenarios are still far from recommending the most appropriate social, economic and environmental reforms to manage groundwater resources through IWRM. Therefore, the knowledge of local people about groundwater resource use and conservation should be seen as important ingredient for the long term in-situ relations between local people and water resources. This is because the projected low flows from inadequate rainfall could be aggravated by the natural and human conditions such as changes in land use and land cover, water demand and use by the local population.

4.2. Intersections of precipitation, groundwater availability and SSWs

Climate change and climate variability are leading to deficiencies in precipitation in aspects of amount, intensity and timing including onset which are resulting in runoff reduction, infiltration and percolation. These changes are further reducing groundwater recharge and subsequently the discharge into wells. Whilst the link between the SSWs and deep water percolation discharge is not confirmed, increased evapotranspiration (ETP) would result in soil water deficiency and subsurface flow which the SSWs have been linked to. This means that the reduction in soil water attributed to reduced flow from ETP, could determine the location, distribution and water inflows of the SSWs (Fig. 6). Similarly, reservoir storage will be affected observed with the six large commercial irrigation infrastructure within the basin which often faced operational challenges, were aggravated by the seasonal dryness. Tono and the Nasia-Nabogo were resilient, with the smaller reservoirs facing the highest losses almost as twice as the large. The resilience of

Fig. 6. Typical SSW, cone-shaped and dug closer to the river bank. Photo by DBK Dovie.

Nasia-Nabogo to meet its water requirements is because it is located upstream relative to other irrigation schemes and therefore has a better inflow and other schemes suffer varying degree of water deficits during very dry years, under increasing water demand. It is evident that increasing water demands under relatively dry years of precipitation poses threats to irrigation activities (Table 3). Notwithstanding, small scale water exploration for irrigation therefore holds significant promise in sustaining year-round cultivation towards reducing farm deprivation and wealth deficit within the White Volta basin (WRC 2011). Whilst extraction rates of groundwater in the White Volta basin have been noted to be too small to affect the regional water balance, groundwater remains potentially sound to partly narrow the irrigation water deficit (Addai et al. 2015; Lutz et al. 2007). Generally, groundwater remains underutilized in Ghana although it holds promise for enhanced agriculture, recognized in the National Water Policy and Irrigation Strategy (Government of Ghana, GoG 2007). However, the scale of underutilization of groundwater (including SSWs), for farming is largely unknown because of the lack of any monitoring scheme to account for its withdrawal as rainfed agriculture and large dams dominate the sector. Therefore, the influence of SSWs over groundwater, its characteristics and links to ecological water demand of the basin are unknown although studies suggest that unsustainable water withdrawals could harm ecosystem services (e.g. Morway et al. 2013; Wichelns and Qadir 2015), which are important features of critical river basins.

Several informal and private groundwater irrigation schemes such as the SSWs adopted by farmers and often routinely unplanned or haphazard are becoming the preferred choice of dry season irrigation strategy. Elsewhere, SSWs are known to potentially lead to improved crop water potential (CWP) and enhanced yield if appropriately understood and managed (Mdemu et al. 2009). The SSWs like other privately initiated small irrigation schemes within the White Volta basin is an important coping strategy in response to water stress, reservoir water deficits and climate change. As the name suggests, SSW is practiced until the peak of the dry season when water in most of the catchments including large dams of the White Volta ran dry. It is also becoming an important feature of small scale irrigation globally, in similar forms in other dry regions such as the Mediterranean which is experiencing increasing drier conditions (Ertürk et al. 2014; Ludwig et al. 2011). The scattered SSWs in the White Volta basin are opportune for monitoring related biophysical impacts on a continuous basis to reduce farm vulnerabilities such as crop failure (Liebe et al. 2005), yet requires understanding the underlying mechanics. It is therefore not surprising that there is no known state level effort in Ghana in particular, to develop and integrate SSWs into formal irrigation.

4.3. Resilience of groundwater, SSWs and irrigation implications

The annual groundwater recharge range in the White Volta basin is considered large enough to sustain groundwater for commercial irrigation during drier periods (de Condappa et al. 2009; Obuobie et al. 2012; WRC 2008). Although the study is consistent with global trends, the growing complex dynamics of poor land management in the White Volta basin could trigger large-scale water resource change (Dovie 2010). The SSWs are known to farmers to be defiant of the upheld convention that the Voltaian aquifers of the White Volta basin have often resulted in dry wells, unless wells are sunk deep enough. Yet, deep wells are costly and not totally feasible in the face of competing priorities of farmers, households and government (Taylor and Tindimugaya 2009). A major observed constraint of the SSWs to farmers had to do with distances of farms from the wells beyond the immediate river banks which affect farmer efficiency, yet some farmers were able to afford motorized pumps for irrigation and the need for technologies such as solar pumps would increase affordability. The SSWs therefore add to the diverse water resource management features of the White Volta basin and northern Ghana to reduce over-dependence on rain fed irrigation linked mostly to the single (unimodal) rainfall pattern which is experiencing continuous protraction.

Subsequently, timing of the onset of the rains is paramount to irrigation because farmers do suffer significant losses when the rains either delay or fall over shorter periods and making SSWs most valuable especially in the absence of drought early warning systems (DEWS). Therefore, White Volta basin has the potential to support smallholder farmers who adopt appropriate rather than expensive and non-affordable farm-level groundwater irrigation initiatives and technologies (Bharati et al. 2008; Giordanoa and de Fraiture 2014). Challenges of efficiency and sustainability remain in (i) design of walls of SSWs, (ii) understanding renewability and distribution, and (iii) real economic returns and uptake, for contemporary irrigation development and extension. However, the failure to overcome the challenges is partially the inability of successive governments to implement a systems approach to irrigation water management which IWRM principles uphold. Thus, water development and management should be based on a participatory approach involving users, planners and policy-makers at all levels including management at the lowest appropriate level, participatory and integrative of multiple sectors (GWP 2004, Hering 2016).

5. Conclusion and way forward

The study reveals various levels of decline in groundwater of the White Volta basin, and the result of the decreasing rate of recharge water in the face of expansive drier conditions related to climate change. Therefore, the exploitation of deep aquifer water for different uses could not be sustained unless recharge has improved. Large reservoirs are drying up and of the six large irrigation schemes that were analyzed, two (Tono and Nasia-Nabogo) met all year requirements for water availability. It is evident that increasing demands under relatively dry years of precipitation poses threats to irrigation activities. The adoption of shallow groundwater has been on the rise to make up for the deficits created by deep aquifer, large reservoirs and surface water deficiencies. The SSWs are dependent on water inflows within the unsaturated zone rather than aquifers. The lowland areas of the basin are solely dependent on the highlands for replenishing storage beyond the rainy season. However, there still exists sufficient groundwater to supplement irrigation water to partially offset losses through surface water, hydrological drought and evapotranspiration. The SSWs are not effective everywhere due to differences in distribution and sustainability of groundwater recharge. The adoption of the SSW practice has significantly served as water safety nets, reduced drudgery amongst women and lengthened growing season for smallholder farmers. Therefore, costly deep groundwater wells are not the only options for groundwater exploration but also the sub-surface water which is recharged in the unsaturated zone is important. Looking forward, there is the need to map and interpret shallow groundwater resources especially SSWs and stake in building resilience. Hence, challenges of data shortage and metrics on harnessing groundwater resources for uses such as the SSWs and its functioning which is largely non-familiar to scientists, in response to climate change and climate variability should be overcome. The need to improve catchment river flow prediction in the basin is important in predicting the impacts of climate change and climate variability calls for sustained computations of potential evapotranspiration (ETP). In all, interpretations and perception of users of groundwater resources, managers and policy makers will make scientific outcomes relevant and rigorous towards using shallow groundwater as important response measure to hydroclimatic stress.

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Appendix A. Supplementary data

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